

POLYIMIDE ADHESION ENHANCEMENT TO POLYIMIDE FILM

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BACKGROUND OF THE INVENTIONFIELD OF THE INVENTION

10 The present invention relates to the manufacture of printed circuit boards having improved interlayer adhesion. More particularly, the present invention pertains to adhesiveless, flexible printed circuit boards having excellent thermal performance and useful for producing high-density circuits.

DESCRIPTION OF THE RELATED ART

15 Printed circuit boards are employed in a wide variety of applications. For example, they can be found inside radio and television sets, telephone systems, automobile dashboards and computers. They also play an important role in the operation of airborne avionics and guidance systems. It is known to use polyimide films in the production of circuit boards because of their excellent flex
20 characteristics and good electrical properties. More particularly, it is common to attach a layer of a conductive metal foil to a surface of a polyimide film to provide a surface upon which a pattern of an electrical conductor can be provided. In such cases, it has been recognized in the art that any movement of the metal foil on the polymeric film could potentially impair the performance of the equipment
25 incorporating the circuit board. To avoid this problem, it is necessary that the conductive metal layer strongly adhere to the polymeric substrate to prevent any shifting of the metal layer on the film.

There have been various efforts in the art to improve the adhesion of metal foils to polymeric substrates in forming printed circuit boards while maintaining good thermal resistance and low cost of manufacture. U.S. patent 4,382,101 offers one proposed solution to this problem wherein a substrate is etched with a plasma etchant and then a metal is vapor deposited onto the etched surface of the substrate. This process requiring the vapor deposition of a metal directly onto an etched surface is very expensive and undesirable. U.S. patent 4,615,763 provides a method of improving adhesion of a photosensitive material to a substrate by selectively etching resinous portions of a substrate comprising a resinous material and an inorganic particulate material. U.S. patent 4,639,285 teaches a process wherein a metal foil is attached to a surface of a synthetic resin substrate via an intermediate silicone-based adhesive layer after treating the substrate surface with a low temperature plasma. The low temperature plasma utilized is an organo-silicon compound with an inorganic gas, such as oxygen. U.S. patent 4,755,424 provides a polyimide film produced from a polyimide containing a dispersed inorganic powder. Particles of the inorganic powder protrude from the film surface to roughen the film. The film surfaces are then treated with a corona discharge treatment to alter the surface chemistry of the film. U.S. patent 4,863,808 teaches a polyimide film coated with a vapor deposited chromium layer, a vapor deposited copper layer, and followed by electroplating with copper. U.S. patent 5,861,192 provides a wet chemistry method with mechanical and projection grinding to increase the adhesion of a polyimide film surface.

The present invention provides an improved solution over those of the prior art. A process for forming printed circuit boards is provided wherein a polymeric film is coated onto at least one surface of a metal foil, followed by laminating the

polymeric surface of the coated metal foil onto at least one etched surface of a substrate. The substrate surface may be etched with either a chemical or plasma etchant, and may comprise either the same or a different material than the polymeric film. The result is a circuit board having high thermal resistance, a pure substrate and low cost of manufacture while avoiding the many undesirable problems associated with wet chemical processing.

SUMMARY OF THE INVENTION

- 10 The invention provides a process for forming a printed circuit board composite comprising:
- a) etching at least one surface of a polymeric substrate;
 - b) coating a first polymeric film onto a surface of a metal foil; and
 - c) laminating the first polymeric film onto the substrate by:
 - 15 i.) laminating the first polymeric film directly onto at least one etched surface of the substrate, or
 - ii.) laminating the first polymeric film onto at least one etched surface of the substrate via an intermediate second polymeric film.
- 20 The invention also provides a printed circuit board composite comprising a polymeric substrate having a first etched surface, a first polymeric film attached to the first etched surface of the substrate and a layer of a metal foil attached to an opposite side of the first polymeric film.
- 25 The invention further provides a process for forming a printed circuit board comprising:
- a) etching at least one surface of a polymeric substrate;

- b) coating a first polymeric film onto a surface of a metal foil;
- c) laminating the first polymeric film onto the substrate by:
- i.) laminating the first polymeric film directly onto at least one etched surface of the substrate, or
 - 5 ii.) laminating the first polymeric film onto at least one etched surface of the substrate via an intermediate second polymeric film;
- d) depositing a photoresist onto the metal foil;
- e) imagewise exposing and developing the photoresist, thereby revealing underlying portions of the metal foil; and
- 10 f) removing the revealed underlying portions of the metal foil.

It is also within the scope of the invention to form multilayered printed circuit boards or composites by incorporating additional polymeric films or metal foil layers. A thorough description of these embodiments is included herein.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention provides a printed circuit board support having improved interlayer adhesion, enhanced thermal stability and excellent electrical insulating properties as compared to the prior art.

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The first step in the process of the invention is to etch at least one surface of a suitable substrate with an appropriate etchant, forming a first etched surface.

Typical substrates are those suitable to be processed into a printed circuit or other microelectronic device. Preferred substrates for the present invention are

25 polymeric substrates and non-exclusively include materials comprising polyester, polyimide, liquid crystal polymers and polymers reinforced with materials such as fiberglass, aramid (Kevlar), aramid paper (Thermount), polybenzoxolate paper or

combinations thereof. Of these a polyimide substrate is the most preferred. Also suitable are semiconductor materials such as gallium arsenide (GaAs), silicon and compositions containing silicon such as crystalline silicon, polysilicon, amorphous silicon, epitaxial silicon, and silicon dioxide (SiO₂) and mixtures thereof. The preferred thickness of the substrate is of from about 5 μm to about 200 μm, more preferably from about 5 μm to about 50 μm.

Appropriate etchants are those which are capable of selectively removing portions of the substrate surface. Preferred etchants for the present invention non-exclusively include plasma etchants and concentrated aqueous etching solutions. Preferred aqueous solutions non-exclusively include Group I or Group II hydroxides which include hydroxides of elements from Groups I or II of the periodic table, such as sodium hydroxide and potassium hydroxide. Ammonium hydroxide may also be used. The useful concentration of an aqueous etchant varies with the particular etchant and the thickness of the substrate to be etched. Typically useful etchant concentrations range from about 5% to about 25 % by weight of the etchant material, preferably from about 10% to about 20%. For example, one useful aqueous etchant is a potassium hydroxide solution having a concentration of from about 8% to about 12% of potassium hydroxide. Also suitable is a sodium hydroxide solution at a concentration of from about 8% to about 16% by weight of sodium hydroxide.

Any plasma etching technique which is suitable for etching polymer substrates may be used. This plasma etchant is a highly charged gas that bombards the film surface with positive and negative charged species causing impurities on the surface to degrade as well as ablating the film surface. These include halogen containing plasma etching materials and oxygen containing plasma etching

materials. The preferred plasma etchant comprises a gaseous mixture of oxygen (O₂) and tetrafluoromethane (CF₄). Preferably the plasma etchant comprises at a mixture of oxygen plasma and tetrafluoromethane plasma comprising least about 3% of tetrafluoromethane, more preferably it comprises from about 3% to about 20% and still more preferably from about 7% to about 20% of tetrafluoromethane with the balance being oxygen. This minimum quantity of tetrafluoromethane is important to prevent any over etching of the substrate.

The etching step of the process of the present invention is accomplished by contacting the polymeric film with the aqueous base etchant or plasma etchant. Etching is conducted by contacting the areas of the substrate to be etched with the etchant material, under conditions sufficient to remove at least about 0.45 μm from at least one surface of the substrate. Such procedures are well known in the art. In another embodiment of the invention, both surfaces of the substrate are etched, allowing additional layers to be added to the printed circuit board support of the invention having superior adhesion to the substrate.

When using an aqueous base etchant, the duration of the etching step is determined based on the chemical composition of the substrate and is generally from about 10 seconds to about 20 minutes in length. For example, when using a KOH etchant, the etching time for a polyimide substrate is from about 20 seconds to about 3 minutes. Preferably the etching solution is maintained at a temperature of from about 40°C to about 65°C. It has been found that neutralizing the surface with a dilute acid, to form a soluble salt, and subsequent rinsing with deionized water, will provide a clean surface. By altering the film residence time, the etch rate can be altered.

When etching is done by plasma etching, it may be performed in a plasma etching chamber as is well known in the art.

5 The next step is to apply a first polymeric film onto a surface of a metal foil to form a coated metal foil. The polymeric film is preferably deposited onto the metal foil as a liquid by coating, evaporation or vapor deposition to allow for control and uniformity of the polymer thickness. Preferred polymeric materials include polyimides, polyesters, polyester containing co-polymers, polyarylene ethers, liquid crystal polymers, polyphenylene ethers, amines, and combinations
10 thereof. Of these, polyimides are the most preferred. In another embodiment of the invention the polymeric film and the polymeric substrate comprise the same polymer.

15 Polyimides are preferred for the polymeric film because they have high electrical strengths, good insulating properties, a high softening point and are inert to many chemicals. Preferred are polyimides having a glass transition temperature (T_g) of from about 160°C to about 320°C, with a glass transition temperature of from about 190°C to about 270°C are preferred. Preferably, the polymeric film will have a thickness of from about 2 μm to about 100 μm , more preferably from
20 about 5 μm to about 50 μm .

The polymeric film may be applied to the metal foil by coating a suitable solution of the polymer onto the foil and drying. For example, a solution may be formed of the polymer and an organic solvent. It is preferred that a single solvent be used
25 in each polymer solution. Useful solvents include acetone, methyl-ethyl ketone, N-methyl pyrrolidone, and mixtures thereof. The most preferred single solvent is N-methyl pyrrolidone. The polymer-solvent solution will typically have a

viscosity ranging from about 5,000 to about 35,000 centipoise with a preferred viscosity in the range of 15,000 to 27,000 centipoise. The solution may comprise from about 10 % by weight to about 60% by weight of polymer, more preferably from about 15% by weight to about 30 % by weight of polymer with the
5 remaining portion of the solution comprising one or more solvents. After application, the solvent is evaporated leaving a polymeric film on the metal foil. Alternatively, a thin sheet of the polymer may be laminated under heat and pressure onto the metal foil. In another embodiment, a molten mass of the polymer material may be extrusion coated onto the metal foil.

10 The polymer film may also optionally comprise a filler material. Preferred fillers non-exclusively include ceramics, boron nitride, silica, barium titanate, strontium titanate, barium strontium titanate, quartz, glass beads (micro-spheres), aluminum oxide, non-ceramic fillers and combinations thereof. If incorporated, a filler is
15 preferably present in an amount of from about 5% to about 80% by weight of the film, more preferably from about 10% to about 50% by weight of the film.

Preferred metal foils for the printed circuit board support of the invention comprise copper, zinc, brass, chrome, nickel, aluminum, stainless steel, iron, gold,
20 silver, titanium and combinations and alloys thereof. Most preferably, the metal foil comprises copper. The metal foil preferably has a thickness of from about 5 μm to about 200 μm , more preferably from about 5 μm to about 50 μm .

Copper foils are preferably produced by electrodepositing copper from solution
25 onto a rotating metal drum as is well known in the art. The side of the foil next to the drum is typically the smooth or shiny side, while the other side has a relatively rough surface, also known as the matte side. This drum is usually made of

stainless steel or titanium which acts as a cathode and receives the copper as it is deposited from solution. An anode is generally constructed from a lead alloy. A cell voltage of about 5 to 10 volts is applied between the anode and the cathode to cause the copper to be deposited, while oxygen is evolved at the anode. This copper foil is then removed from the drum and cut to the required size.

The metal foil may optionally be roughened, such as by micro-etching, by being electrolytically treated on the shiny side to form a roughened copper deposit, and/or electrolytically treated on the matte side to deposit micro-nodules of a metal or metal alloy on or in the surface. These nodules are preferably copper or a copper alloy, and increase adhesion to the polymer film. The surface microstructure of the foil may be measured by a profilometer, such as a Perthometer model M4P or S5P which is commercially available from Mahr
Feinpruef Corporation of Cincinnati, Ohio. Topography measurements of the surface grain structure of peaks and valleys are made according to industry standard IPC-TM-650 Section 2.2.17 of the Institute for Interconnecting and Packaging Circuits of 2115 Sanders Road, Northbrook, Illinois 60062.

In the measurement procedure, a sample measurement length l_m over the surface is selected. An R_z is determined, where R_z is defined as the average maximum peak to valley height of five consecutive sampling lengths within the measurement length l_m . An R_a , or average roughness, is also determined where R_a is defined as the arithmetic average value of all absolute distances of the roughness profile from the center line within the measuring length l_m . The surface treatments are carried out to produce a surface structure having peaks and valleys which produce roughness parameters wherein R_a ranges from about 1 to about 10 microns and R_z ranges from about 2 to about 10 microns.

The optional surface treatments on the shiny side of the foil are preferably carried out to produce a surface structure having peaks and valleys which produce roughness parameters wherein Ra ranges from about 1 to about 4 microns, preferably from about 2 to about 4 microns, and most preferably from about 3 to about 4 microns. The Rz value ranges from about 2 to about 4.5 microns, preferably from about 2.5 to about 4.5 microns, and more preferably from about 3 to about 4.5 microns.

- 10 The optional surface treatments on the matte side of the foil are preferably carried out to produce a surface structure having peaks and valleys which produce roughness parameters wherein Ra ranges from about 4 to about 10 microns, preferably from about 4.5 to about 8 microns, and most preferably from about 5 to about 7.5 microns. The Rz value ranges from about 4 to about 10 microns, preferably from about 4 to about 9 microns, and more preferably from about 4 to about 7.5 microns.

- 20 An optional copper deposit on the shiny side of the foil will preferably produce a copper deposit of about 2 to about 4.5 μm thick to produce an average roughness of 2 μm or greater. An optional nodule deposit on the matte side preferably will have a roughness Rz as made of about 4 to about 7.5 μm . The micro-nodules of metal or alloy will have a size of about 0.5 μm . Other metals may be deposited as micro nodules if desired, for example, zinc, indium, tin, cobalt, brass, bronze and the like. This process is more thoroughly described in U.S. patent 5,679,230. In 25 the preferred embodiment of the invention, the shiny surface preferably has a peel strength ranging from about 0.7 kg/linear cm to about 1.6 kg/linear cm, more preferably from about 0.9 kg/linear cm to about 1.6 kg/linear cm. The matte

surface preferably has a peel strength ranging from about 0.9 kg/linear cm to about 2 kg/linear cm, more preferably from about 1.1 kg/linear cm to about 2 kg/linear cm. Peel strength is measured according to industry standard IPC-TM-650 Section 2.4.8 Revision C.

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Also, prior to applying the polymeric film to the metal foil, a thin metal layer may optionally be electrolytically deposited onto either side of the metal foil. After applying the polymeric film to the metal foil, and either before or after lamination to the etched substrate, a thin metal layer may optionally be deposited onto the foil surface opposite the polymeric film by coating, sputtering, evaporation or by lamination onto the foil layer. Preferably the optional thin metal layer is a thin film and comprises a material selected such as nickel, tin, palladium platinum, chromium, titanium, molybdenum or alloys thereof. Most preferably the thin metal layer comprises nickel or tin. The thin metal layer preferably has a thickness of from about 0.01 μm to about 10 μm , more preferably from about 0.2 μm to about 3 μm .

Next, the coated metal foil is laminated to the etched surface of the substrate. This step may be conducted either by laminating the first polymeric film directly onto at least one etched surface of the substrate, or by laminating the first polymeric film onto at least one etched surface of the substrate via an intermediate second polymeric film. Of these, lamination via an intermediate second polymeric film is preferred. Including this second polymeric film has been found to even further increase the interlayer adhesion between the metal foil and the substrate. Preferably, the second polymeric film comprises a material such as those suitable for the first polymeric film, more preferably the first and second polymeric films comprises the same polymer. The second polymeric film

preferably has a thickness of from about 2 μm to about 100 μm , more preferably from about 5 μm to about 50 μm . The second polymeric film is preferably deposited onto etched surface of the substrate as a liquid by coating, evaporation or vapor deposition to allow for control and uniformity of the polymer thickness.

- 5 Subsequently, the metal foil and substrate are laminated together such that the first and second polymeric films contact each other.

- Lamination is preferably conducted by autoclave lamination, vacuum hydraulic pressing, non-vacuum hydraulic pressing or by hot roll lamination. Lamination
10 may also be conducted using an ADARATM press which comprises heating the metal foil by an amount sufficient to soften the polymeric film by flowing an electric current through the foil and attaching the polymeric film to the substrate. When using a vacuum press, lamination is preferably conducted at a minimum of about 275°C, for about 30 minutes. Preferably, the press is under a vacuum of at
15 least 28 inches of mercury, and maintained at a pressure of about 150 psi.

- The resulting laminate will have a peel strength that varies widely based on the thickness of the polymeric layers and the amount of substrate surface removal. For example, in order to obtain a laminate having an adequate peel strength of at least
20 4 lbs./inch, it is necessary to remove at least 0.45 μm from the substrate surface. The peel strength can also be improved increasing the thickness of the polymeric layers. For example, having a polyimide coating of about 12 μm on a copper foil will obtain a laminate having a peel strength of about 7 lbs./inch, while a 30 μm coating will give a laminate having a peel strength of about 9 lbs./inch. This is
25 reflected in the Examples below. Preferred peel strengths range from at least about 4 lbs./inch, more preferably from at least about 5 lbs./inch, and most preferably from at least about 6 lbs./inch. Although the peel strength for this

invention has no upper limit, a peel strength of about 12 lbs./inch represents a practical peel strength upper limit.

Once the coated metal foil has been laminated onto the etched substrate, the next
5 step is to selectively etch away portions of the metal foil or optional thin metal
layer, forming an etched pattern in the foil or optional thin metal layer. This
etched pattern is formed by well known photolithographic techniques using a
photoresist composition. First, a photoresist is deposited onto the metal foil or
optional thin metal layer. The photoresist composition may be positive working
10 or negative working and is generally commercially available. Suitable positive
working photoresists are well known in the art and may comprise an o-quinone
diazide radiation sensitizer. The o-quinone diazide sensitizers include the o-
quinone-4-or-5-sulfonyl-diazides disclosed in U. S. Patents Nos. 2,797,213;
3,106,465; 3,148,983; 3,130,047; 3,201,329; 3,785,825; and 3,802,885. When o-
15 quinone diazides are used, preferred binding resins include a water insoluble,
aqueous alkaline soluble or swellable binding resin, which is preferably a novolak.
Suitable positive photodielectric resins may be obtained commercially, for
example, under the trade name of AZ-P4620 from Clariant Corporation of
Somerville, New Jersey as well as Shipley I-line photoresist. Negative
20 photoresists are also widely commercially available.

The photoresist is then imagewise exposed to actinic radiation such as light in the
visible, ultraviolet or infrared regions of the spectrum through a mask, or scanned
by an electron beam, ion or neutron beam or X-ray radiation. Actinic radiation
25 may be in the form of incoherent light or coherent light, for example, light from a
laser. The photoresist is then imagewise developed using a suitable solvent, such

as an aqueous alkaline solution, thereby revealing underlying portions of the metal foil or optional thin metal layer.

Subsequently, the revealed underlying portions of the metal foil or optional thin
5 metal layer are removed to the substrate through well known etching techniques,
such as acid or alkaline etching, while not removing the portions underlying the
remaining photoresist. Suitable etchants non-exclusively include acidic solutions,
such as cupric chloride (preferable for etching of nickel) or nitric acid (preferable
for etching of tin). Also preferred are ferric chloride or sulfuric peroxide
10 (hydrogen peroxide with sulfuric acid). If the optional thin metal layer is
included, this step will reveal the portions of the metal foil underlying the etched
off portions of the thin metal layer. This patterned thin metal layer will define an
excellent quality etch mask for etching the metal foil layer with high accuracy and
precision. If the optional thin metal layer is not included, this step will reveal the
15 portions of the polymeric film layer underlying the etched off portions of the
metal foil.

If the optional thin metal layer is included, the next step is to remove the revealed
underlying portions of the metal foil by etching while not removing the portions
20 of the metal foil underlying the non-removed portions of the optional thin metal
layer. Suitable etchants for removing the metal foil non-exclusively include
alkaline solutions, such as ammonium chloride/ammonium hydroxide. This
circuit board may then be rinsed and dried. The result is a printed circuit board
having excellent resolution and uniformity, good thermal resistance and excellent
25 interlayer adhesion.

After the circuit lines and spaces are etched through the optional thin metal layer and metal foil, the remaining photoresist can optionally be removed either by stripping with a suitable solvent or by ashing by well known ashing techniques. The photoresist may also be removed after etching the optional thin metal layer,
5 but prior to etching the metal foil.

In another preferred embodiment of the invention, the above processes may be repeated on an opposite side of the substrate. A second opposite surface of the polymeric substrate may be etched in addition to the first etched surface and an
10 additional layer of the first polymeric film material is coated onto a surface of an additional metal foil. The additional layer of the first polymeric film is then attached to the second opposite etched surface of the substrate. This step may be conducted either by laminating the additional first polymeric film directly onto the second opposite etched surface of the substrate or by laminating the additional
15 first polymeric film onto the second opposite etched surface of the substrate via an additional layer of the second polymeric film material, as described above.

The second opposite surface of the substrate is preferably etched following the same procedures as described above, and may be etched either prior to lamination
20 of the first polymeric film to the first etched surface of the substrate, or after such lamination takes place. Further, after attaching another first polymeric film on an additional metal foil to the second opposite etched surface of the substrate, a thin metal layer may optionally be deposited onto the outer surface of the additional metal foil following the techniques described above. The additional metal foil
25 and optional thin metal layer may then optionally be etched using a photoresist as described above to form a printed circuit pattern in the second metal foil. In the preferred embodiment of the invention, the first and second polymeric films may

comprise the substantially same material, as may the first and additional metal foils.

The following non-limiting examples serve to illustrate the invention.

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EXAMPLE 1

A polyimide film substrate is plasma treated with a highly charged plasma etchant gas mixture of oxygen (O_2) and tetrafluoromethane (CF_4), the gas mixture
10 containing 7% CF_4 . The plasma etchant bombards the film surface with positively and negatively charged species causing impurities on the film surface to degrade and ablating the film surface. This etching step removes approximately $0.7\ \mu m$ of material from the surface of the film. Separately, a copper foil is coated with a continuous layer of polyimide to achieve a layer thickness of $8\ \mu m$. The
15 coated copper foil and the etched substrate are then laminated together in a vacuum press at about $275^\circ C$, for about 30 minutes, under a vacuum of at least 28 inches of mercury, and maintained at a pressure of about 150 psi. The resulting laminate has a peel strength of about 4 lbs./inch.

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EXAMPLE 2

A polyimide substrate is plasma treated under similar conditions as in Example 1 using an etchant consisting of a gas mixture of oxygen (O_2) and tetrafluoromethane (CF_4), containing 7% CF_4 . However, the etching step is conducted to remove approximately $0.475\ \mu m$ of material from the surface of the film. After
25 laminating the etched substrate together with a similar coated substrate as in Example 1, the resulting laminate exhibits a peel strength of about 4.5 lbs./inch.

EXAMPLE 3 (COMPARATIVE)

Example 1 is repeated except using an etchant having only 3% CF₄ and rather than limiting the etching step to remove approximately 0.7 μm of material from the surface of the film, the etching step is continued for about 15 minutes. This results in an overetched laminate having reduced peel strength. The peel strength of the laminate after fifteen minutes is only about 0.5 lbs./inch.

EXAMPLE 4

Example 1 is repeated, but rather than coating a copper foil with only an 8 μm layer of polyimide, a 12 μm coating of polyimide is applied. This resulting laminate exhibits peel strength of about 7 lbs./inch.

EXAMPLE 5

Example 1 is repeated, but rather than coating a copper foil with only an 8 μm layer of polyimide, a 30 μm coating of polyimide is applied. This resulting laminate exhibits peel strength of about 9 lbs./inch.

EXAMPLE 6

A 25 μm polyimide substrate is etched on both sides using similar etching conditions as in Example 1. Two copper foils are coated, each with a 12 μm layer of a polyimide and laminated to opposite sides of the substrate under conditions similar to Example 1. The resulting laminate is a polyimide dielectric of about 50 μm, having a peel strength in excess of 7 lbs./inch.

EXAMPLE 7

A 25 μm polyimide substrate is etched using similar etching conditions as in Example 1. A copper foil is coated with a 12 μm layer of a polyimide and is

laminated under conditions similar to Example 1 to the etched substrate via an intermediate second polyimide film of about 12 μm . The resulting laminate is a polyimide dielectric of about 50 μm , having a peel strength in excess of 7 lbs./inch.

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While the present invention has been particularly shown and described with reference to preferred embodiments, it will be readily appreciated by those of ordinary skill in the art that various changes and modifications may be made without departing from the spirit and scope of the invention. It is intended that the
10 claims be interpreted to cover the disclosed embodiment, those alternatives which have been discussed above and all equivalents thereto.